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Analysis of the JSF Engine Competition

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Abstract

Typically dual-source competition involves more than one producer building the same build-to-print (BTP) hardware design. A more analytically challenging case occurs when two contractors develop and produce two different designs to meet the same functional requirements. Such a case was examined by the Institute for Defense Analyses in a forward-looking cost and economic analysis of the Joint Strike Fighter alternative engine program.

We first considered the additional costs required to execute a competitive program between the F135 (Pratt & Whitney) and F136 (General Electric) engines. While the start-up costs (in the JSF case, an additional development program) and loss-of-learning and rate effects associated with an additional production line are analogous to those in a BTP competition, there is an array of other costs associated with the support of an additional engine design. These were accounted for in IDA's analyses, including additional government management, initial spares, and depot/training/support equipment. Also included were additional operations and support (O&S) costs such as depot-level reparables, sustaining engineering, and contractor program management (SE/PM); software support, and engine component improvement programs.

All of these costs were considered as the investment required to establish competition. To have the potential for recovering this investment over the JSF's life cycle, both procurement and contractor-provided O&S services would have had to be competed effectively, and such a competition would have had to save about 18 percent of total procurement and O&S cost.

Two-line summary

This paper describes a forward-looking cost and economic analysis of the JSF alternative engine program performed by the Institute for Defense Analyses (IDA).

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14. ABSTRACT

Typically dual-source competition involves more than one producer building the same build-to-print (BTP) hardware design. A more analytically challenging case occurs when two contractors develop and produce two different designs to meet the same functional requirements. Such a case was examined by the Institute for Defense Analyses in a forward-looking cost and economic analysis of the Joint Strike Fighter alternative engine program. We first considered the additional costs required to execute a competitive program between the F135 (Pratt & Whitney) and F136 (General Electric) engines. While the start-up costs (in the JSF case, an additional development program) and loss-of-learning and rate effects associated with an additional production line are analogous to those in a BTP competition, there is an array of other costs associated with the support of an additional engine design. These were accounted for in IDA?s analyses, including additional government management, initial spares, and depot/training/support equipment. Also included were additional operations and support (O&S) costs such as depot-level reparables, sustaining engineering, and contractor program management (SE/PM); software support, and engine component improvement programs. All of these costs were considered as the investment required to establish competition. To have the potential for recovering this investment over the JSF?s life cycle, both procurement and contractor-provided O&S services would have had to be competed effectively, and such a competition would have had to save about 18 percent of total procurement and O&S cost.

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1. Introduction and Approach

Typically, dual-source competition involves more than one producer building the same build-to-print hardware design. A more analytically challenging case occurs when two contractors develop and produce two different designs to meet the same functional requirements. An example of this type of competition was examined by the Institute for Defense Analyses (IDA) in a forward-looking cost and economic analysis of the Joint Strike Fighter (JSF) alternative engine program. This paper shows that in such a case a broader range of costs and other factors must be considered when describing the probable effects of competition.

The John Warner Defense Authorization Act for Fiscal Year 2007 directed the Secretary of Defense to select a Federally Funded Research and Development Center to conduct an independent cost analysis of the JSF engine program. The Office of the Under Secretary of Defense (Acquisition, Technology and Logistics) selected IDA to perform that study. This paper highlights some of the more analytically interesting aspects of the study while describing a prototype for similar future studies. The full study is documented in Woolsey et al. (2007).

The JSF engine program had been structured and executed to allow effective competition between two engines, the F135 (being developed by Pratt & Whitney (P&W)) and the F136 (developed by the Fighter Engine Team (FET) of General Electric (GE) and Rolls Royce until cancellation in 2011). The engines were designed to be physically and functionally interchangeable, giving the federal government flexibility in its selections. The planned production quantities were high enough (over 3000 installed engines) that half of the planned purchase would represent a large production quantity to either contractor team. Although the F135 had a head start in development and planned production relative to the F136, the differences were not significant enough to saddle the F136 with a competitive disadvantage. Past experiences with engine competitions led to the expectation that the two engines would be price-competitive, an important ingredient in a successful competition. These programmatic characteristics are necessary for competition, but are an insufficient basis for a decision about whether a competitive program would benefit the government. Our analysis examined the costs and potential benefits of the sole-source and competitive approaches to providing engines for the JSF program.

In approaching the problem we first considered the investments required to execute a competitive engine program. We then determined the savings that would have to be achieved as a result of the competition to recover this investment and compared these savings to what has been seen in other competitive programs. Finally, we evaluated potential benefits of competition beyond price reductions. The ground rules and assumptions used for the analyses were as follows:

- Analysis was for unique components only (no lift fan, nozzle, or roll posts that would be shared across both designs)

- Procurement profiles for US and international partners were from the 2006 JSF Selected Acquisition Report
- Analysis does not include costs and benefits to international customers or future US applications
- Costs through FY 2007 were considered sunk
- JSF program office ground rules provided the baseline for Operations and Support (O&S) cost analysis
- The life-cycle period was 2008–2065

Calculations were performed on a net present value (NPV) basis as well as in constant fiscal year 2006 dollars (FY06$) and then year dollars (TY$). In addition to a baseline case reflecting the program of record, multiple excursions were also considered.

2. Investments Required for a Second Engine Program

Execution of a second engine program requires additional costs in all phases of the program life cycle. These investments include both direct investments, such as development costs for the second engine, and opportunity costs, such as the loss of economies inherent in larger production quantities. These additional costs would be evident in support activities as well as in the traditional investment phase of the acquisition cycle. A major challenge was enumerating all aspects of cost touched by the existence of a second engine design.

A. Development

For System Design and Development (SDD) to be accomplished the F136 design needed to be completed; it would have had to go through both ground and flight testing; and it would have had to be managed and integrated into the JSF system by Lockheed Martin, federal government, and P&W personnel. Costs were estimated by IDA for the following activities:

- Remaining F136 FET SDD contract costs
- Government ground test
- Government and Lockheed Martin personnel supporting F136 development
- Fuel and Other
- Remaining P&W support to the FET

The most important part of the remaining F-136 development cost was the FET SDD contract. We examined the schedules and associated budget plan for both the F135 and F136 SDD contracts using a model developed from historical data. In both cases, we found a substantial risk

that the Initial Service Release milestone for each engine would be delayed for around one year; given this, a higher cost estimate for the F136 was used as an excursion in the NPV analyses.

B. Procurement

During production, the presence of a second engine would reduce the quantities P&W produced, consequently reducing the economies that would have accompanied a larger purchase. Scale economy effects included both cost progress (learning) and production rate impacts. The existence of a second engine also impacts procurement costs through the need to establish support infrastructure for the second engine design.

Quantifying production cost differences meant creating independent cost estimates for the F135 and F136. As the F135 was in a more advanced state of development, data were available describing the costs of manufacturing flight test engines. We used F135 Flight Test Engine (FTE) #3 actual data at the component level. Component learning curves from P&W's F119 (the F-22 engine that was a precursor to the F135) FTE and production experience were applied. The few components that were common between the F119 and F135 shared learning quantities. The F136 was more challenging, as no meaningful test hardware costs were available. Instead we developed component cost estimating relationships (CERs) from cost data for previous GE engines (the F101, F110, F404, and F414); components modeled were the fan, core, low-pressure turbine, augmentor, and final assembly/other. F136-specific design data for each component were used along with historic GE price-level learning curves to produce F136 production costs.

The resulting cost estimates reflected a sole-source environment for both engines. Given these cost estimates and the timing of production schedules, including "education buys" for the F136 (early procurement lots not under competition), we found the cost disadvantage of the F136 at the first competitive lot to be smaller than those calculated for earlier successful competition programs.

Once we had learning curves for each engine, calculating the loss of learning associated with a split buy compared to an F135 sole-source program was a straightforward exercise. To do this, we assumed a 50/50 split of production engines between the two models. Note that in this calculation, no competition effects were taken into account—the learning curves were based on sole-source experience. The impact of competition on learning curves is taken into account later in the analyses.

Another cost difference considered was the change in overhead costs paid by the government, given a second engine producer. Moving engines from the P&W to FET facilities would affect total overhead costs paid by the US government (including programs other than the JSF); we modeled this effect by assuming:

- 50 percent of total costs were overhead,
- 30 percent of overhead was fixed, based on defense aerospace averages, and

- Effects at GE facilities also applied to Rolls Royce content.

Business base projections came from public data. The analysis showed an increase in overhead cost for dual-sourcing the JSF engine of $228 million (FY06$) over the period 2006–2034. This may modestly overstate the effect because some fixed overhead effects were captured in the learning curve analysis (learning curve slopes would be marginally shallower if fixed costs were excluded in their calculation).

The cost of initial spare parts and establishing repair depot capabilities would also be increased by the introduction of a second engine. For initial spares, a second engine program creates higher spares cost because of higher unit engine production costs and the requirement for two spares pools. The costs of depot establishment for a second engine were based on F119 cost experience and contractor, program office, and IDA estimates from previous studies. These estimates were adjusted for engine quantity, number of depot locations, and engine attributes.

C. Operations and Support (O&S)

In the support phase of the system's life cycle, the second engine would also increase the costs of supporting the JSF engine inventory. As was the case for procurement, costs were estimated for both a single engine fleet and a fleet split evenly between the two engine designs. For presentation, we broke the costs into three categories: (1) variable O&S (costs that vary with the number of flying hours), (2) fixed O&S (those that do not vary based on activity), and (3) component improvement programs (CIP). The CIPs are not strictly O&S costs, as they are paid for by Research, Development, Test & Evaluation (RDT&E) funding; however, they are oriented to solving in-service problems.

The most important variable O&S costs are depot-level reparables (DLR) and consumables. The drivers of DLR/consumables costs were reliability and repair costs. IDA used a DLR CER and data at the engine module level to estimate the total DLR and consumables costs. The relationships were calibrated using data from the JSF program office, the Air Force, and historical data for the F-15 and F-16 programs. The analysis accounted for reliability growth as well as the effects of aging and diminished parts supplier sources. DLR/consumables costs were higher for the two engine case because maturity with respect to reliability was reached two years later, and repair costs (including consumables) tended to scale with unit production costs, which in turn were higher for the two-engine case.

Fixed O&S costs included Sustaining Engineering/Program Management (SE/PM) and post-deployment software support. SE/PM annual fixed costs were based on F-119 SE/PM experience adjusted for engine complexity, configuration, and program scale. Software support was estimated using the Constructive Cost Model (COCOMO) maintenance model structure, with estimates driven by Source Lines of Code (SLOC), SLOC change and growth rate, productivity, and labor rates. Fixed O&S costs essentially double with the second engine.

Statistical analyses of historical annual CIP funding found three important cost drivers:

- The size of the engine inventory—the larger the inventory, the greater the payoff for a given upgrade;
- Complexity and size of the engine being supported—engines that are costlier to build are generally costlier to improve; and
- Time trend effects—as engine development practices improve, CIP costs decrease, and as individual engine models mature, CIP requirements decrease.

Average annual CIP funding was estimated at $26 million (FY06$) per engine type; peak funding of $40 million per engine type would occur in FY 2016. Because of the inventory effects, the two-engine CIP costs were slightly less than twice the sole source F135 case.

Table 1 presents the O&S costs for the sole source purchase and a 50/50 split, as well as the delta associated with adding the F135 engine.

Table 1. Operations and Support Cost Summary

	One Engine (F135) (FY06$B)	Two Engines (50/50 Split) (FY06$B)	Delta (FY06$B)
DLRs and Consumables	19.6	21.2	1.7
SE/PM	0.9	1.7	0.8
Software Support	0.4	0.9	0.4
Engine CIP	1.4	2.6	1.2
Other [a]	11.1	11.7	0.4
Total	33.5	38.0	4.6

Note: Values do not add due to rounding

[a] Other includes maintenance manpower, modifications, contractor logistics support, and indirect support

D. Investment Summary

Our estimate of the sum of these investments, including opportunity costs, is $8.8 billion in constant FY 2006 dollars, before accounting for the price reductions that competition might produce. Of this investment, we estimate that $2.1 billion would occur in fiscal years 2008–2012. This is primarily development cost, while the residual amount (total less O&S and 2008–2012 costs) of $2.1 billion is mostly procurement cost.

3. Potential Price Benefits from Competition

We examined the history of two engine competitions—the so-called Great Engine War (GEW) and the dual-sourcing of the F404 engine. We also surveyed past studies of competition savings.

As in most studies of competition savings, the key analytical tool applied was the learning/price improvement curve. Figure 1 presents a generic example of its application to calculate competition savings.

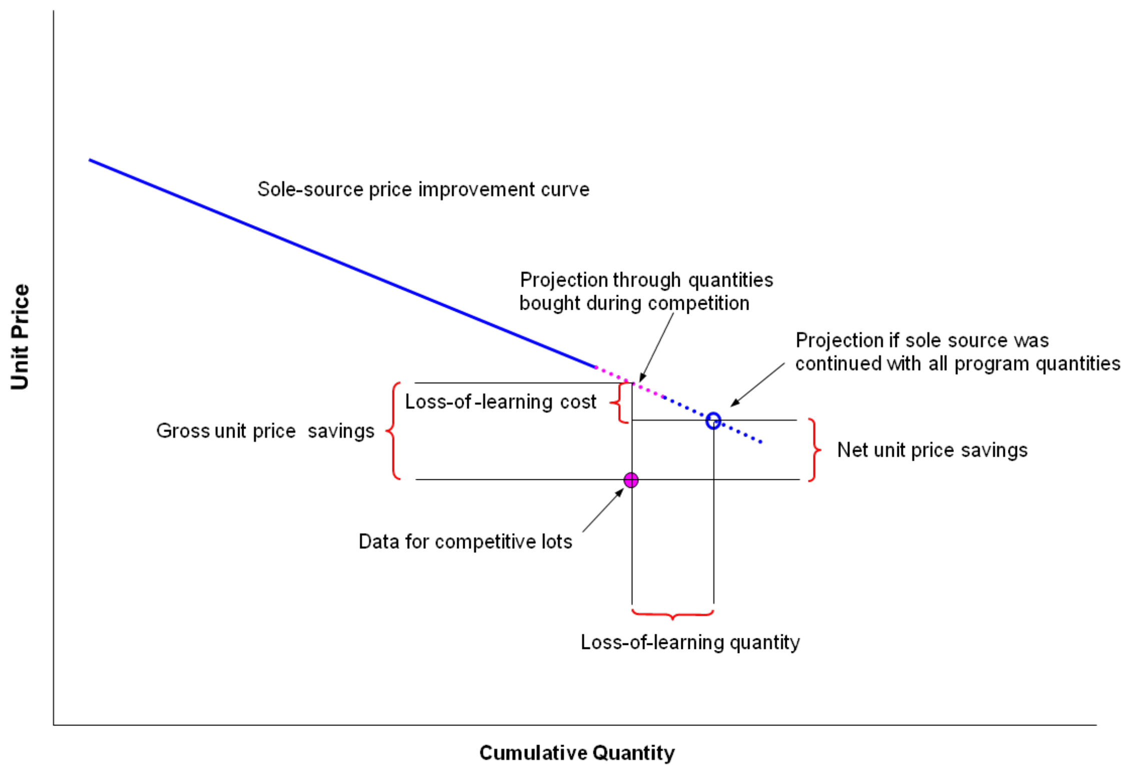

Figure 1. Generic Example of Competition Savings Analysis

In our application, competition savings percentages are the percentage displacement of the observed competition cost data from the projected sole-source price improvement curve. This displacement corresponds to the gross unit price savings in Figure 1. Note that the loss-of-learning costs shown above were accounted for in our analyses as investment costs. Past study results could only be useful for reference if the gross savings percentages were calculated in a consistent fashion and the calculations were transparent.

The GEW was the US Air Force-initiated competition in 1984 between P&W and GE for 2000 F-15 and F-16 fighter engines. Analyses of competition savings for the GEW were complicated by the specifics of the engine programs. This led us to two different approaches for estimating competition savings. The P&W F100-100/200 was the incumbent engine in the F-15

and F-16 programs. Parallel with the start of competition was the introduction of a substantially upgraded version of that engine, the F100-220. Given this, direct comparisons between the competition prices and the sole-source price improvement curve could not be made. The introduction of new components caused the F100-220 to experience a substantial loss of learning with a retracing of the original F100-100/200 price improvement curve. When we adjusted for this, we found prices for the normalized F100-220 to be significantly below those for the sole-source F100-100/200. An alternative approach was to compare prices for GE's entry—the F110-100—with those derived from the sole source F100-100/200 learning curve; this methodology also showed significant price savings.

The F404 engine competition was a dual-sourcing of engines used on US Navy F/A-18 aircraft. In this case, P&W built engines to the GE F404 design and competed in four competitive procurement years, 1986 through 1989. The competition was subsequently terminated. The approach used in estimating savings followed closely the generic methodology presented in Figure 1.

Our analyses showed gross savings ranging from 11 to 18 percent of engine procurement costs. We also examined available studies of competitions that the Department of Defense (DOD) conducted over the past 30 years for a variety of other systems. Unfortunately, we were not able to extract results from them that could be used as a primary means of evaluating the likely savings of a JSF engine competition. There were methodological differences among the studies, and some studies did not describe clearly how the analyses were performed and what was included in the stated "savings due to competition."

4. Break-Even Analysis

IDA employed a discount rate of 3.00 percent, based on 30-year maturity in Appendix C of Office of Management and Budget Circular A-94; this translated the total investment of $8.8 billion in FY 2006 dollars into an NPV of $5.1 billion. To break even financially—or, in other words, to offset fully the NPV of investment estimated to establish the alternative JSF engine—would require a savings rate during the production phase of 40 percent.. Savings of this magnitude are implausible, considering the 11 to 18 percent savings realized in previous engine competitions. If O&S costs were effectively competed in addition to procurement costs, the required savings rate would fall from 40 percent of procurement costs to 18 percent of total costs. Excursions reflecting other likely scenarios did not change the break-even savings percentage appreciably. For example, higher F136 SDD costs associated with a schedule stretch resulted in a break-even percentage savings of 19 percent, while a 50 percent increase in buy quantities resulted in a break-even percentage savings of 16 percent.

Because the DOD has not typically linked procurement and O&S costs in a single competition, we found no historical data with which to estimate plausible O&S savings under such an acquisition strategy. Competition might affect prices for O&S services in a range of ways. Without explicitly competing support services, some O&S savings would flow naturally from the savings in a procurement competition. Spare parts, for example, could be expected to see some savings through this mechanism. Elements of O&S can also be tied to the procurement competition by adding O&S metrics to the procurement selection criteria. To take O&S competition a step further, all elements of O&S services could be packaged into a single acquisition covering design improvements, spare parts, and logistics support. This model is widely used by the commercial airline industry, which routinely bundles support contracts with the initial engine purchases, bringing support services directly into the purchase competition. We understood at the time that the JSF program office intended to use an acquisition strategy that ties some elements of O&S costs to the procurement competition.

5. Other Benefits of Competition

Competition had the potential to bring benefits in addition to price reductions. One such potential benefit was fleet readiness. The JSF will dominate the US fighter attack force structure as no previous platform has. Having two independent engine types could reduce the impact of an engine anomaly that could ground or reduce the readiness of large numbers of aircraft. Also, competition might have improved contractor responsiveness. For example, it is generally agreed that the government received improved contract terms, cooperation, and overall responsiveness from contractors when competition for fighter engines was introduced during the 1980s.

Finally, continuation of the F136 program would have ensured that GE would remain in the industrial base for high-performance military aircraft engines. Without the F136, GE’s incentive and ability to maintain the skills unique to these types of engines is less certain, although GE would remain a leading supplier of commercial aircraft engines.

6. Conclusions

Creating competition by developing, procuring, and maintaining a second engine would require an investment of about $8.8 billion in constant FY 2006 dollars. Approximately half of these costs would occur in the operations phase of the program. To have the potential for recovering this investment over the JSF’s life cycle, both procurement and O&S services would have to be competed effectively, and such a competition would have to save about 18 percent of total procurement and O&S cost. The study results show the importance of a comprehensive

accounting of all costs that would be affected by the introduction of a second hardware design as part of a competitive strategy.

Author Biographies

Jim Woolsey

Jim Woolsey is the Deputy Director – Performance Assessment, AT&L, Performance Assessment and Root Cause Analysis. He is on an Intergovernmental Personnel Act (IPA) assignment from the Institute for Defense Analyses (IDA), where he is an Assistant Director of the Cost Analysis and Research Division. Prior to his employment at IDA he was Lead F/A-18C/D Structures Engineer, Naval Air Systems Command. Mr. Woolsey has a BS in Aerospace Engineering from the Virginia Polytechnic Institute and State University and an MBA from George Mason University.

Harold Balaban

Harold Balaban is a research staff member in the Cost Analysis and Research Division of the Institute for Defense Analyses. He specializes in applying reliability, maintainability, and logistics factors to estimate the life cycle cost of major defense systems. Prior to his employment at IDA, Dr. Balaban was Director of Advanced Analysis at ARINC Research Corporation, Annapolis, Maryland. He has a Ph.D. degree in statistics from The George Washington University.

Kristen Guerrera

Kristen Guerrera is a Research Associate in the Cost Analysis and Research Division at IDA. Her work at IDA has supported numerous independent life cycle cost estimates and analyses of alternatives, with a focus on operation and support costs and modeling and simulation. She has also performed numerous analyses for the Department of Veterans Affairs including an assessment of VBA's quality program, an analysis of the variance in disability compensation across states, an assessment of personnel requirements, and several workload forecast modeling studies. She has a B.S. degree in Industrial and Systems Engineering from Binghamton University and an M.S. degree in Operations Research and Industrial Engineering from The Pennsylvania State University.

Bruce Harmon

Bruce Harmon is an Adjunct Research Staff Member at the Institute for Defense Analyses where he has worked for over 25 years. Bruce has extensive experience modeling the costs and schedules of various aerospace systems, as well as analyses of other acquisition issues. He is a Ph.D. Candidate in Economics at American University, Washington DC.

References

Woolsey, J. et al. (2007). (U) *Joint strike fighter (JSF) engine cost analysis: final report* (IDA Paper P-4232). Alexandria, VA: Institute for Defense Analyses. Unclassified (PI/LR/FOUO).

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Outline

- **Background**
- Additional investments for second engine
- Potential price benefits
- Break-even analysis
- Other benefits of competition
- Conclusions

Background

- The John Warner Defense Authorization Act for Fiscal Year 2007 directed the Secretary of Defense to select a Federally Funded Research and Development Center (FFRDC) to conduct an independent cost analysis of the Joint Strike Fighter (JSF) engine program
- The Office of the Under Secretary of Defense for Acquisition, Technology and Logistics selected the Institute for Defense Analyses (IDA) as the FFRDC
- This briefing summarizes the findings of the 2007 IDA study* in non-proprietary form

*Woolsey, J. et al. (2007). (U) *Joint Strike Fighter (JSF) Engine Cost Analysis: final report* (IDA Paper P-4232). Alexandria, VA: Institute for Defense Analyses. Unclassified (PI/LR/FOUO).

JSF Engine Program

- Planned to provide competition between two interchangeable engines
  - F135
    - Pratt & Whitney (P&W) engine
    - Started System Design and Development (SDD) in 2001
    - Flew on the first F-35 aircraft in December 2006
  - F136
    - Fighter Engine Team (FET)—General Electric (GE) and Rolls Royce—engine
    - In SDD since 2005
    - Scheduled for first flight in October 2010 (2007 plan)
    - SDD contract canceled and program terminated in 2011
- Program structure was consistent with successful competitions
  - Planned quantities were high (half of the planned total represents a large quantity by historical standards)
  - History suggested the FET would be price competitive with P&W

Analysis Scope

- ***Investments to create a second engine:*** an estimate of the costs required to develop, procure, and maintain a second engine, before accounting for the benefits of competition
- ***Potential price benefits:*** a review of estimated savings produced by competition in previous programs
- ***Break-even analysis:*** an estimate of the savings that competition must produce to offset the required investment
- ***Other benefits of competition:*** an evaluation of potential benefits other than price reductions that might be produced by competition
- ***Conclusions***

Ground Rules and Assumptions

- Analysis for unique components only (no lift fan, nozzle, roll posts)
- Procurement profiles for U.S. and international partners are from the 2006 JSF Selected Acquisition Report
- Analysis did not include costs and benefits to international customers or future U.S. applications
- Costs through FY 2007 were considered sunk
- JSF program office ground rules provided baseline for Operations and Support (O&S) cost analysis
- Life-cycle period, 2008–2065

Outline

- Background
- **Additional investments for second engine**
  - **System Design and Development (SDD)**
  - **Procurement**
  - **Operations and Support**
- Potential price benefits
- Break-even analysis
- Other benefits of competition
- Conclusions

SDD Investment: Costs to Complete

- Largest portion of cost was for the remainder of the FET SDD contract
- Other resources were required to support F136 development
    - JSF prime contractor personnel – support for integration efforts
    - P&W costs –common component integration/hardware
    - Government personnel – program office
    - Fuel and other

Procurement Investment Overview

- Quantity effects (Lost Learning)
  - Assumed 50/50 split in competition quantities
- Rate effects (Overhead)
- Below flyaway
  - Initial spares
  - Depot establishment
  - Other below flyaway
- Government personnel

IDA produced independent cost estimates for both the F135 and F136, including learning curve slopes

Procurement Cost Estimates

F135

Used F135 Flight Test Engine (FTE) #3 actual data

- Costs available by component
- Applied F119 FTE and component learning curve experience to project into future
- Accounted for F119 commonality

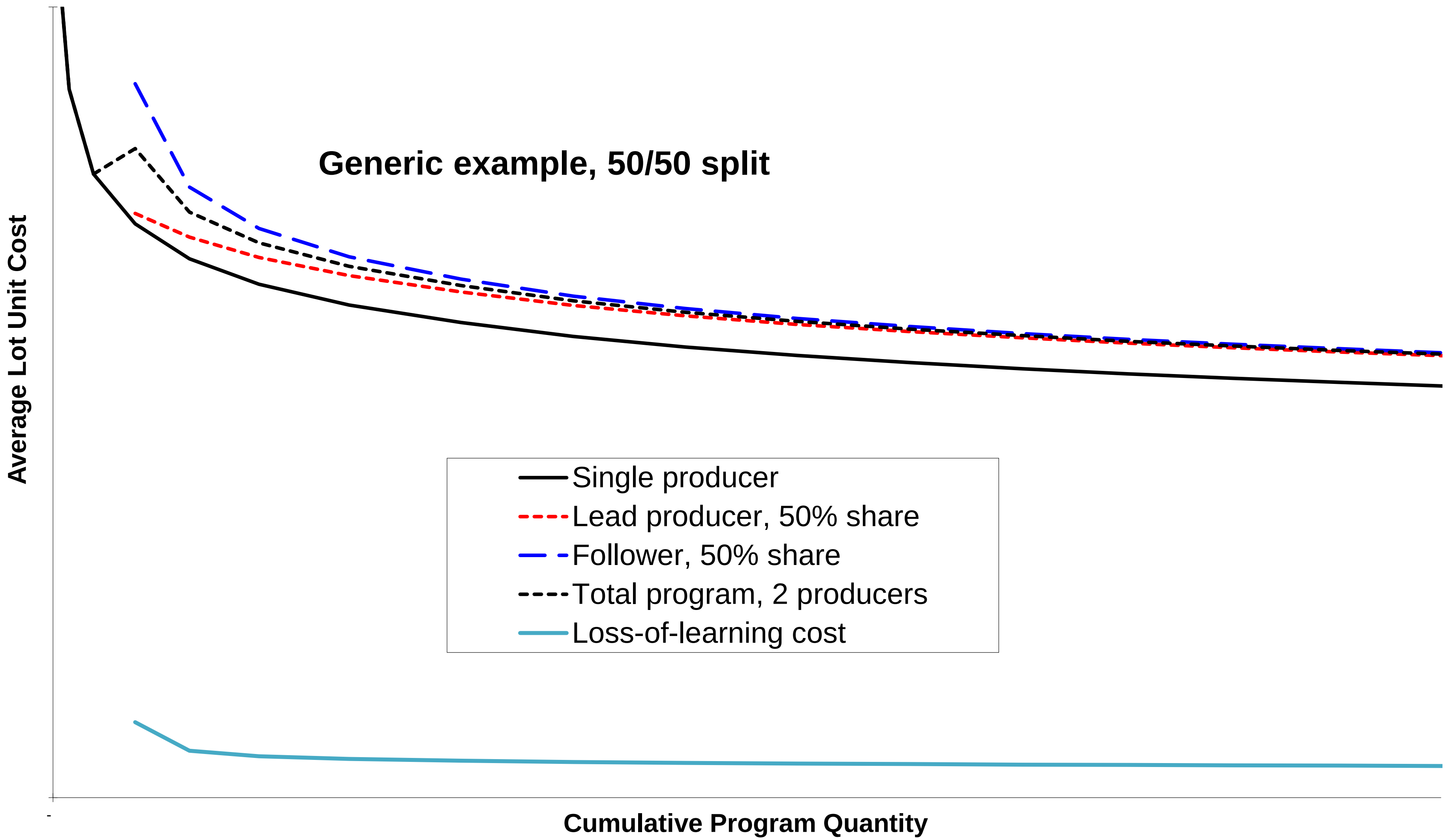
F136

Created component Cost Estimating Relationships (CERs) from previous GE engines

- F101, F110, F404, and F414
- Fan, core, low-pressure turbine, augmentor, and final assembly/other
- Applied F136-specific design data for each component
- Used historic GE price-level learning curves

Estimates indicated the F136 would be price competitive with the F135

Lost Learning



Used sole-source price levels and learning curve slopes to calculate loss-of-learning cost

Overhead Effects

- Moving engines from P&W to FET facilities would affect total overhead costs paid by the U.S. government (including programs other than the JSF); we modeled this effect by assuming:
  - 50% of total costs are overhead
  - 30% of overhead is fixed, based on defense aerospace averages
  - Effects at GE facilities also apply to Rolls Royce content
- Business base projections are from public data
- Analysis shows an increase in overhead cost for dual sourcing the JSF engine
  - $228 million in 2006–2034
  - This may modestly overstate the effects because some overhead impact is captured in the price improvement curve analysis
- Refining this analysis would not materially change overall results

Procurement: Below Flyaway

- ***Initial spares***
  - Two-engine program creates higher spares cost because of higher procurement cost and requirement for two spares pools
  - IDA spares estimating relationship considers:
    - Beddown, procurement cost, and engine removal rates
    - Base re-supply time, depot demand rates, and depot turnaround time
    - Joint Program Office sparing assumptions and spares availability requirement
  - Used JSF program office plan of one spare whole engine per squadron
- ***Depot establishment (and other costs)***
  - Based on F119 cost experience and contractor, F-22 program office, and previous IDA estimates
  - Adjusted for quantity of engines, number of depot locations, and configuration and cost complexity

Operations and Support Investment: Overview

- Variable operations and support
- Fixed operations and support
  - Sustaining engineering/program management
  - Software support
- Component Improvement Program

Variable Operations and Support

- ***Depot-level reparables (DLRs) and consumables:***
  - Sources – contractors, JSF program office, and the U.S. Air Force were sources for reliability and repair cost data
  - Reliability – reliability demand rate estimates were based on Joint Program Office data, P&W data, and aging experience of legacy engines
  - Engine maturity – date of maturity (200,000 flight hours) slips from FY 2015 to FY 2017 in a 50/50 split
  - Repair cost – used repair cost CER based on F-15 and F-16 repair-to-replacement price ratios; used estimated yearly prices as baseline for repair cost, straight-lined at procurement end
  - Maintenance creep – used to increase repair cost in later life to account for aging equipment, reduced quantities, and parts availability issues
- ***Other:***
  - Maintenance manpower – based on Manpower Estimate Reports verified with IDA IMEASURE model
  - Remaining cost elements – based on F119 cost information adjusted for configuration, complexity, and scale of program

Fixed Operations and Support

- ***Sustaining Engineering/Program Management (SE/PM):*** estimated annual fixed cost based on F-119 SE/PM experience and estimated future costs, adjusted for engine complexity and configuration and program scale
- ***Post-Deployment Software Support:*** estimated annual fixed cost using Constructive Cost Model (COCOMO) maintenance model structure with the following input: Source Lines of Code (SLOC), SLOC change and growth rate, productivity, and labor rates

Component Improvement Program

- Annual Component Improvement Program (CIP) funding estimate captures effects of:
  - Size of the engine inventory – the larger the inventory, the greater the payoff for a given upgrade
  - Complexity and size of the engine being supported – engines that are costlier to build are generally costlier to improve
  - Time trend effects:
    - As engine development practices improve, CIP costs decrease
    - As individual engine models mature, CIP requirements decrease
- Estimated average annual CIP funding is $26 million (FY06$) per engine type
- Estimated peak funding of $40 million per engine type occurs in FY 2016

Operations and Support Cost: Summary

	One Engine (F-135) (FY06$B)	Two Engines (50/50 Split) (FY06$B)	Delta (FY06$B)
DLRs and Consumables	19.6	21.2	1.7
SE/PM	0.9	1.7	0.8
Software Support	0.4	0.9	0.4
Engine CIP	1.4	2.6	1.2
Other[a]	11.1	11.7	0.4
Total	33.5	38.1	4.6

Note: Values do not add due to rounding

[a] Other includes maintenance manpower, modifications, contractor logistics support, and indirect support

Second Engine Investment: Summary

- Total investment
  - **$8.8B** constant FY 2006
  - **$5.1B** Net present value (NPV)
- Investment breakdown (FY 2006 dollars)
  - 2008–2012: **$2.1B** (mostly SDD)
  - Operations and Support (O&S): **$4.6B**
  - 2013–2065 residual: **$2.1B** (mostly procurement)

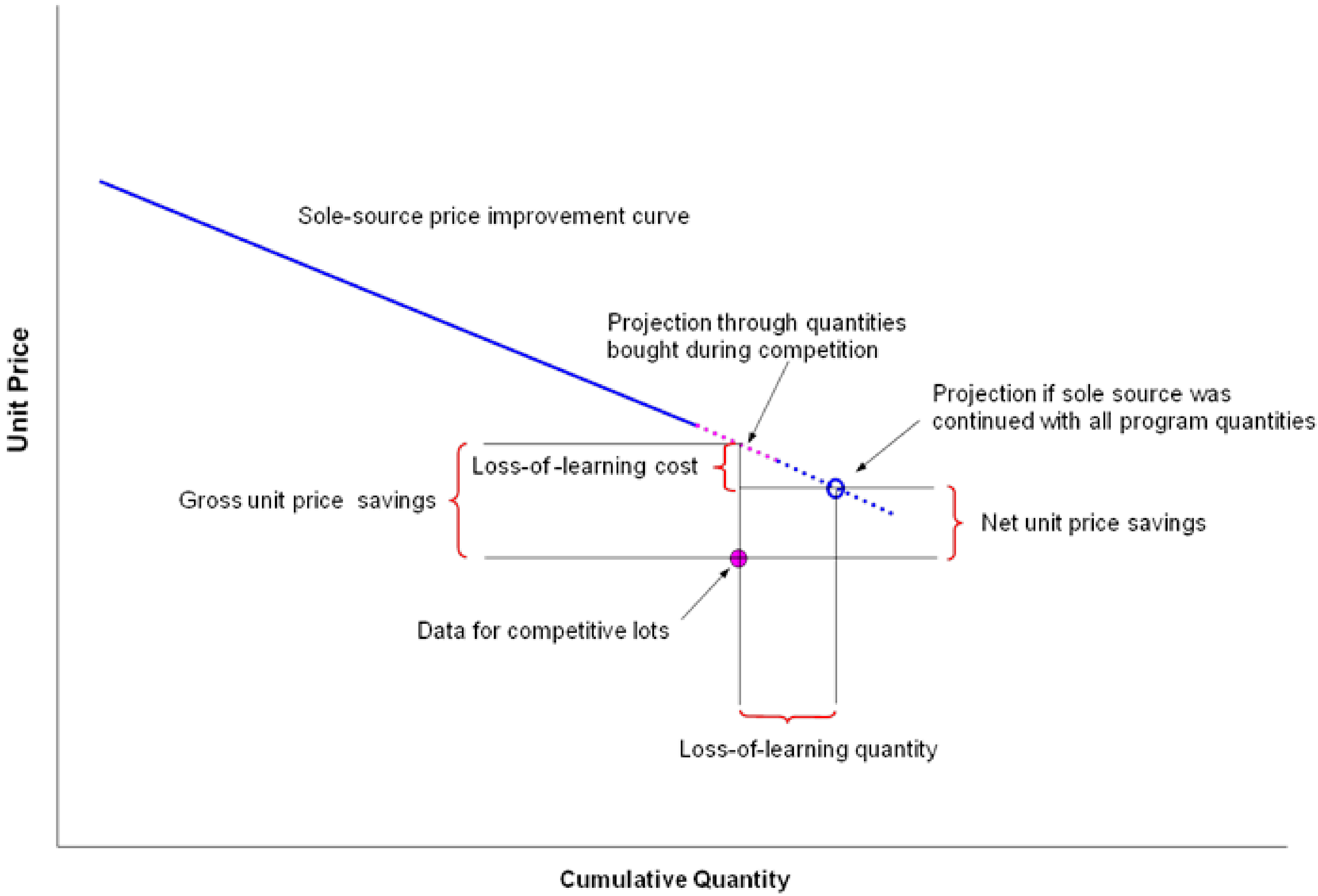
Outline

- Background
- Additional investments for competition
- **Potential price benefits**
- Break-even analysis
- Other benefits of competition
- Conclusions

Price Benefits of Competition

- Examined the potential price benefits of competition by analyzing two competitive engine programs
  - Circa 1984: P&W and GE competed for F-16 and F-15 fighter engines (Great Engine War)
  - Circa 1987: P&W used GE design to build F404 engines for the F/A-18
- Reviewed previous studies of competition benefits, but found them to be inconsistent in methodology and supporting material

Generic Example of Competition Savings



- Gross unit price savings were of interest for our analysis
- Loss-of-learning costs accounted for as investment

IDA Estimate of Unit Cost Reductions in Engine Competitions

- ***Great Engine War (GEW):*** IDA estimated cost reductions using two methods
  - Modeled F100-220 as an upgrade of the F100-100 and found estimated savings due to competition
  - Compared the F110 with competition to the F100 without competition
- ***F404 engines:*** IDA estimated GE price reduction during F404 dual sourcing

Competition savings estimates were 11–18%

Outline

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Break-Even Analysis

- Required savings from competition: IDA calculated the percentage by which costs must be reduced for second-engine investment to be recovered
  - NPV of savings to offset $5.1B NPV of investment
  - Year-by-year competition
- Competition for procurement: savings calculated on procurement costs only; assumes no mechanism for competition savings in O&S
  - 40% savings on ≈$13B NPV base to offset total investment
  - Not plausible, given analysis of historical programs
- Competition for procurement and O&S: savings calculated on procurement and O&S costs
  - 18% savings on ≈$29B NPV base to offset total investment
  - Range of 15–25% for alternative assumptions

Savings in O&S required for break-even

Competition for Support Services

- Support costs are typically more than half of life-cycle costs and normally incurred in a sole-source environment
- Cost savings from procurement competition will flow to some support costs (spare parts, depot-level repair materials, modifications, etc.)
- Competition would ensure that these support cost savings become support price reductions
- Some competition can be created by using award criteria to tie support elements to procurement (warranties, Performance Based Logistics price quotes, etc.)
- 70–80% of commercial aircraft engines are purchased with support service contracts, which implies that packaged competition is the best value solution for airlines
- JSF program office intends to create an acquisition strategy that ties O&S costs to the procurement competition
- We found no data with which to benchmark potential O&S savings

Outline

- Background
- Additional investments for competition
- Potential price benefits
- Break-even analysis
- **Other benefits of competition**
- Conclusions

Other Potential Benefits of Competition

Competition could produce benefits in the following areas:

- Technical risk
- Product quality
- Force readiness
- Contractor responsiveness
- Industrial base

Competition and Technical Risk

- Because the engine designs were independent:
  - Risks were different
  - Probability of obtaining an engine that meets all requirements would be increased by competition
  - Competition creates other options (e.g., single source on one variant with competition on others)
- Same end might be achieved at lower cost by adding money to existing program
- Sustaining competition would require investment in any deficient engine

Our analysis of the effect of competition on technical risk was inconclusive

Competition and Engine Reliability

- Engines that competed in the GEW were more reliable than the predecessor F100-100 engine
- The competitive engines were not more reliable than their non-competitive contemporaries, the F404 and TF30
- Reliability/durability benefited from changes in the engine development process in the mid-to-late 1970s
  - Accelerated mission testing
  - Four-step development process, incorporating more durability testing
  - Initiation of Engine Structural Integrity Program, damage-tolerant design

The historical evidence was inconclusive as to whether competition has improved engine reliability

Readiness and Engine Grounding Events

- Engine programs have had grounding events that reduced fleet readiness
- Significant examples include:
  - AV-8B
    - 10 events since 2000
    - Most severe event affected 2/3 of the fleet for as long as a year
  - B-1B
    - Entire fleet grounded from December 1990–February 1991
    - Last plane returned to service April 1991
- Presence of two engine types would decrease the impact of similar events on future fighter force readiness

Contractor Responsiveness

- Contractor responsiveness was the primary motivation for the GEW; it is generally agreed that responsiveness improved as a result
- GEW accounts report poor responsiveness from P&W
  - Failure to correct reliability problems
  - High spare parts prices
  - Debatable contract interpretations
  - Negotiating positions during competition
- Evidence of competition's effect can be seen in contract terms negotiated during the GEW
  - Fixed price development contracts
  - Firm price initial production
  - Warranties
  - Data rights for spare parts

IDA

GE: Skills Retention

- Some skills and technologies are unique to high-performance military engines (e.g., low observables, flight envelope, thermal management)
- Cancellation of the F136 might threaten these skills at GE:
  - GE's incentive to maintain such skills would depend on potential future business
  - Bomber replacement and Unmanned Aerial Vehicle/Unmanned Combat Aerial Vehicle are prospects, but uncertain
- Mechanisms for retaining skills include:
  - Retaining individuals with expertise
  - Documenting processes
  - Obtaining DOD Science and Technology funding, which has been done in the past (ADVENT program is a current example)
- There would inevitably be losses of individual and collective knowledge:
  - Some of this could be re-purchased if needed

Other Benefits: Summary

- Analysis of the effect of competition on technical risk is inconclusive
- Effect of procurement competition on product improvement and technical innovation is inconclusive
- A second engine would reduce the impact of an engine grounding event on operational readiness
- History has shown that competition makes contractors more responsive
- A second engine would ensure that GE remains in the fighter engine industrial base

Outline

- Background
- Additional investments for competition
- Potential price benefits
- Break-even analysis
- Other benefits of competition
- **Conclusions**

Conclusions

- Direct investments and opportunity costs inherent in executing a second engine program total $8.8 billion, of which $2.1 billion occurs in years 2008–2012.
- If competition only yields procurement savings, it would have to produce savings of 40% on those costs, an implausible rate compared to the 11–18% savings found in previous engine competitions.
- If O&S costs were effectively competed in addition to procurement, the required savings rate would fall to 18% of total costs.
- Because the Department of Defense has not typically linked O&S costs to procurement competition, we found no historical data with which to benchmark plausible O&S savings.
- Competition had the potential to bring benefits in addition to reduced prices:
  - Force readiness
  - Contractor responsiveness
  - Industrial base breadth

Backups

Lessons Learned

- The JSF engine competition as structured met the necessary conditions for a viable competition
- However, competition between two engine designs presented challenges for economic success
  - Support costs are an important portion of engine lifecycle costs
  - Having two designs requires additional support infrastructure and delays reliability maturation
  - There is a limited track record for engine support competition in DOD
  - Many of the advantages of having two engine designs are not quantifiable as cost savings
- Competition may be easier to justify economically in other cases
  - Equipment types where O&S costs are a small portion of life cycle costs
  - Competition between producers of build-to-print items where support costs are not impacted

Analysis of SDD Contracts

- Examined cost risk on SDD contracts by evaluating F135 and F136 schedule projections
  - Focused on Initial Flight Release (IFR) and Initial Service Release (ISR) milestones
  - Used historical programs to develop Time Estimating Relationship (TER)
  - Compared F135 and F136 to resulting TER
- Schedules appear modestly optimistic based on prior expenditure patterns
- Analysis included an excursion for a SDD extension to show effect of potential F136 schedule slip

One-Time Competition for Life-Cycle Costs

- ***Advantages:***
  - Maximizes the stakes of the competition, potentially encouraging large contractor investments
  - Avoids costs inherent in maintaining two production lines and support infrastructures
- ***Disadvantages:***
  - Contract would have to cover more than 40 years and exceed $60 billion
  - Contract would include extraordinary risks due to inflation, buy quantities, growth engines, aircraft usage, labor rates, etc.
  - Contractor could not assume these risks, so the contract would contain myriad exception clauses
  - Contract would become a series of negotiations with a sole source, eliminating much of the competition's value
  - Contractor would have an incentive to "buy-in" at an unsustainable price, anticipating future renegotiation (similar to Total Package Procurement contracts, which typically have been unsuccessful)

One-time competition case
was not analyzed quantitatively

Operations and Support Cost: Summary

	One Engine (F-135) (FY06$B)	Two Engines (50/50 Split) (FY06$B)	Delta (FY06$B)
DLRs and Consumables	19.6	21.2	1.7
Maintenance Manpower	2.9	2.9	0.0
Contractor Logistics Support	2.9	3.2	0.2
Modifications	3.4	3.7	0.3
Indirect Support	1.2	1.2	0.0
Support Equipment Replacement	0.7	0.7	0.0
Sustaining Engineering Support	0.9	1.7	0.8
Software Support	0.4	0.9	0.4
Engine CIP	1.4	2.6	1.2
Total	33.5	38.1	4.6